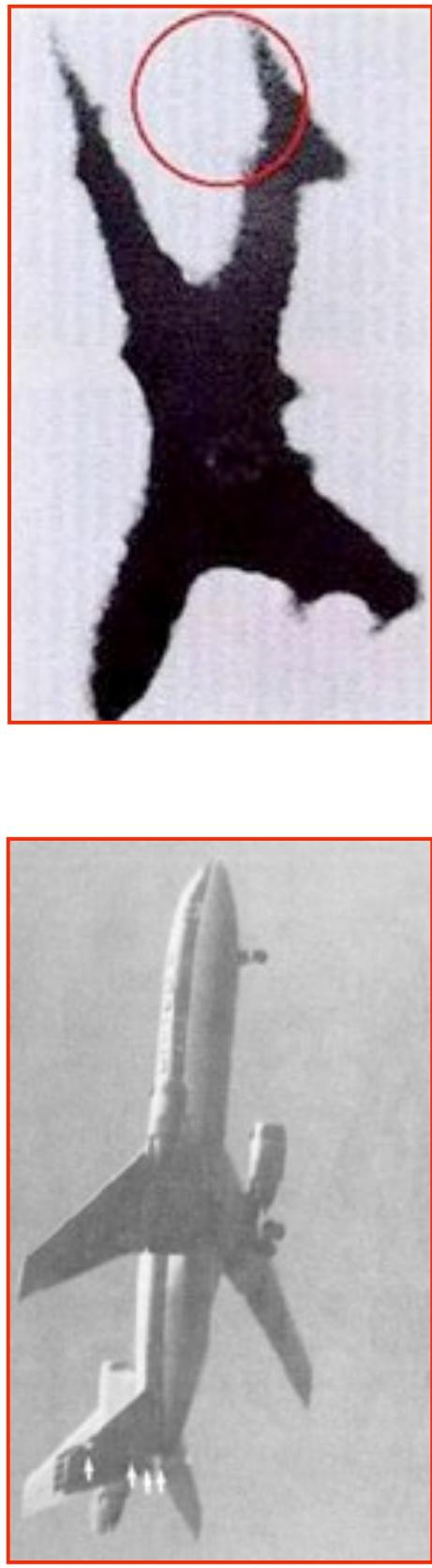


# Aircraft Control Using Engine Thrust



## A History of Learning TOC Real-Time

Jennifer H. Cole

NASA Dryden Flight Research Center

# Learning from History...



- Loss-of-control events
- Causes include
  - Flight control system failures
  - Mechanical cable binding, hydraulic leak
  - In-flight structural failures
  - Hostile intent
- Significant loss-of-control events
  - Commercial: 747, 737, DC-10, L-1011, A-300
  - Military: A-10, B-52, F/A-18, C-5

# Aircraft Control Using Engine Thrust

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- TOC - Throttles Only Control
- TOC is
  - Piloting technique
  - No software or hardware
  - Historically successful in saving lives

**TOC history in loss-of-control events...**

# Past TOC Accidents/Incidents

created from FWB 01-16g

<u>Accidents</u>	Aileron/ Spoiler	Flaps	Rudder	Elevator	Stabilizer	Engines	Cause
→ UAL DC-10	no	no	no	no	no	center out	fan disk/hyd
→ JAL B747	no	yes	no	no	no	all OK	aft bulk/hyd
→ USAF C-5A	yes	yes	no	no	no	all OK	cargo ramp/hyd
→ USAF B-52H	yes	yes	no	no	yes	all OK	hyd leak/tail
Turkish DC-10	yes	?	no	no	no	all OK	door/cables/hyd
USN F/A-18 <i>Incidents</i>	no	no	no	no	no	all OK	hyd act leak
USAF A-10	yes	yes	no	no	no	all OK	AAA/cables
→ USAF B-52G	yes	yes	no	no	yes	all OK	hyd leak/tail
Delta L-1011	yes	yes	yes	yes	one side hardover	all OK	jammed stab
→ DHL A300	no	no	no	no	no	all OK	SAM/hyd

# 1972: DC-10 American Airlines

- Flight 96 was climbing through 11,750 feet at 260 KIAS
- Flight crew felt a ‘thud’ and degraded controls
- The crew managed to regain control of the plane and safely land
  - Sluggish elevator response, no rudder control was available
  - TOC using reverse thrust kept the aircraft on the runway
- Separation of cargo door = rapid decompression = failure of the cabin floor over the bulk cargo compartment.
  - Rudder and 50% of the elevator, stabilizer control were lost
  - Minor fuselage damage
  - Substantial damage to the leading edge and upper surface of the left horizontal stabilizer.

# May 1974: USAF B-52H

- Wright Patterson Air Force Base, OH
- Developed hydraulic leak - no tail controls
  - Stab trim for speed control, spoilers for roll control
- Crew quickly learned how to use *throttles* and airbrakes to control pitch
- Crew flew for 30 minutes, decided to attempt landing
  - Lowered gear, phugoid caused aircraft to lose 8000 feet
- Crew again attempted a landing, but hit hard
  - All 8 crew members walked away
  - Aircraft was destroyed by fire
- As a direct result, TOC procedures were developed for this exact scenario and are **practiced by B-52 crews to this day**



# April 1975: USAF C-5A

- Initial mission of Operation Babylift
- Departed Saigon, South Vietnam
- 328 total onboard, including 243 orphans
- 23000 feet: Structural failure at rear ramp
  - Sudden decompression = severed rudder, elevator cables and loss of 2 hydraulic systems
  - Crew had no tail control
- Functional controls
  - One aileron, spoilers
  - *Engines* for pitch control



# April 1975: USAF C-5A

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- Pilots wrestled with the controls using TOC
- Crew made a practice landing at 10000 ft
  - *Engines* for pitch control
  - Wing spoilers and 1 remaining aileron for roll control
- Crew descended to 4000 feet to prepare for landing
  - Again, gear drop initiated a phugoid
- Rate of descent increased rapidly during approach
- Aircraft slammed down in a rice paddy 3 miles short of runway
- Overall, 175 of the 328 aboard survived
- Worst single non-combat U.S. military aviation disaster

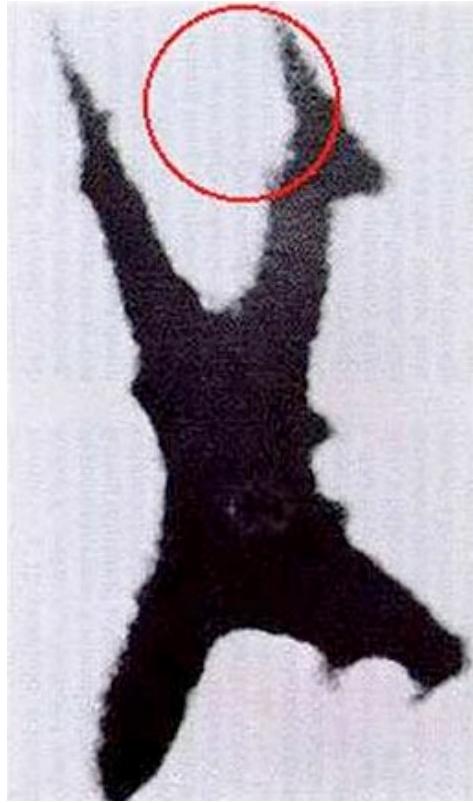
# 1981: USAF B-52G

- Warner Robins AFB, Georgia
- Developed hydraulic leak
  - Subsequently lost all tail controls
- Crew followed established hydraulics-off procedure
  - Used engines and spoilers for control
- The aircraft hit hard and broke fuselage, but was later repaired
- All onboard survived with no injuries



# August 1985: JAL 123 B-747

- Tokyo with 509 onboard
- 24000 ft: aft bulkhead failed
  - Severed 4 sets of hydraulic control lines (no conventional control)
- Crew flew for 30 minutes using TOC
- Eventually crashed into a mountain
- 505 passengers perished, 4 survived



# JAL 123 Survivor Story

Survivors included a flight attendant:

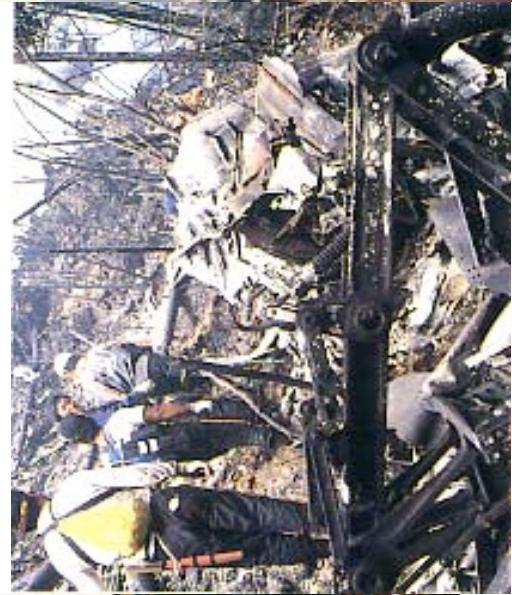
- “There was a sudden loud noise, somewhere to the rear and overhead. It hurt my ears and the cabin filled with white mist... There was no sound of any explosion, but ceiling panels fell off, and oxygen masks fell down.” Then she felt the aircraft going into a falling leaf mode.

Some victims survived impact, but succumbed to exposure during the night



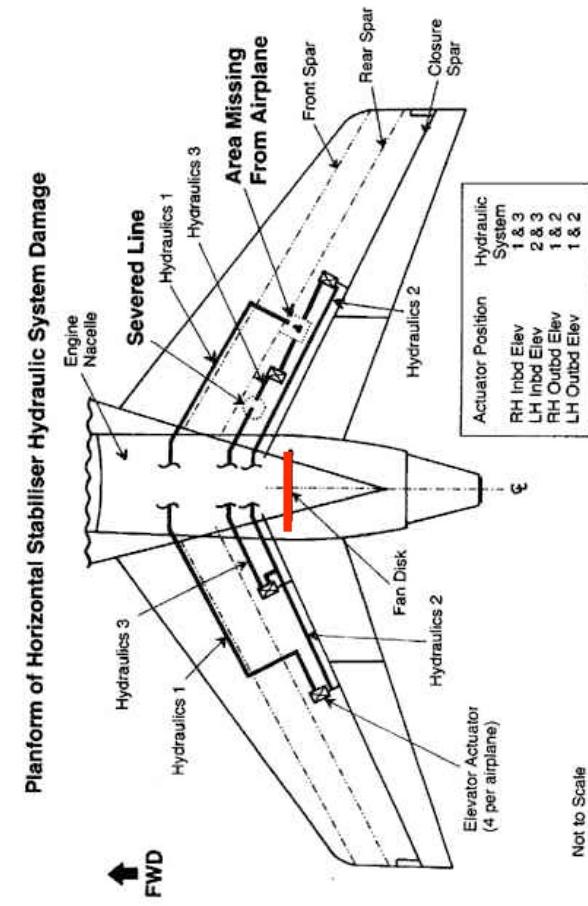
# JAL 123 Investigation Findings

- Further investigation revealed:
  - Tail strike 7 years earlier had damaged rear pressure bulkhead, which was then improperly repaired
  - Accident prompted Boeing to re-inspect aft bulkhead repairs.
  - Ironically, UAL pilot Denny Fitch heard of the JAL 123 incident and spent some time learning TOC on his aircraft, the DC-10. It would later come in handy...



# July 1989: UAL 232 DC-10

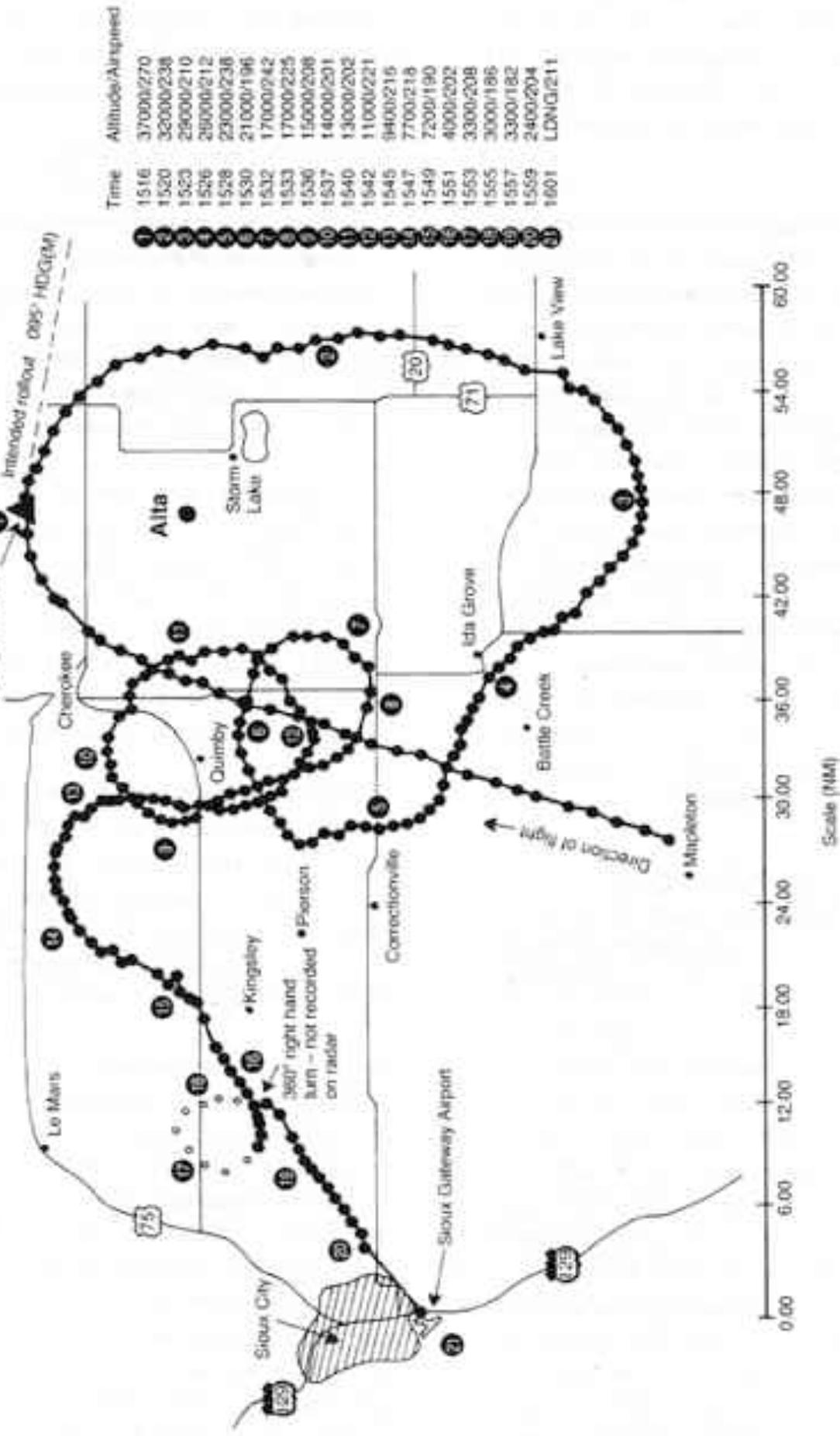
- 37000 feet and 296 onboard: uncontained No.2 (tail) engine failure
  - Shrapnel from fan blade severed lines to all 3 hydraulic systems
- Crew discovers all conventional control is gone
  - Only the two wing engines are operational - TOC is only option
- Crew decided to attempt landing in Sioux City, Iowa



# UAL 232 DC-10

Ground Track from Radar Plot

Note - right-hand turns



# UAL 232 DC-10

- Crew learned TOC real-time with the help of Denny Fitch
- Remarkable teamwork and crew resource management, exceptional experience level, uncanny timing and placement, and extraordinary luck contributed to a survivable crash-landing
  - Al Haynes, Captain of UAL 232, still travels the country to tell the story
  - Miraculously, 185 survived



# UAL 232 DC-10



# Eastwind 517 B-737

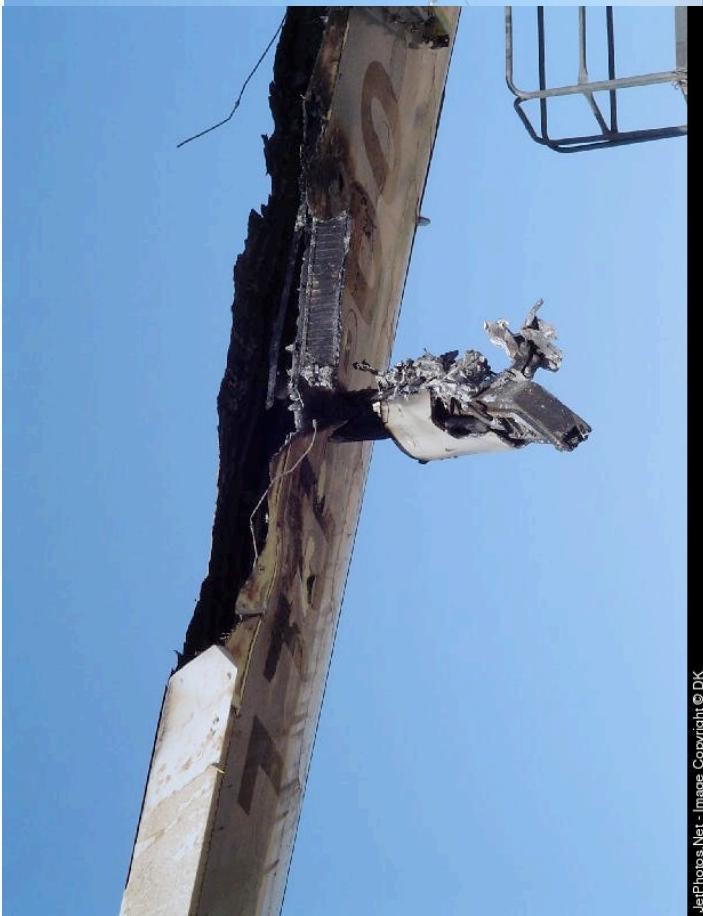
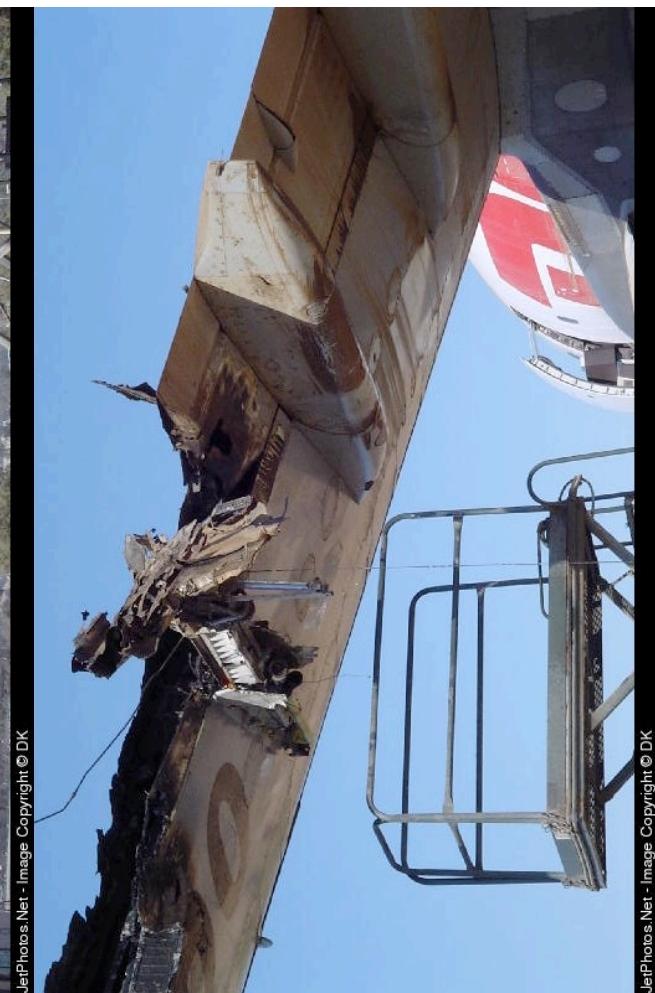
- 4000 feet and 53 onboard: Uncommanded roll to the right
  - Pilot initially felt a rudder 'bump' to the right, then the aircraft suddenly rolled to the right
- Pilot applied opposite rudder, but it felt stiff
  - Then he used opposite aileron and asymmetric power to maintain control
- Emergency declared and checklist performed
  - Part of checklist included turning off yaw damper
  - Aircraft became controllable again
- Safe landing performed
- Further investigation uncovered previous problems with uncommanded rudder deflections
  - Rudder 'bumps' during departure and difficulty trimming aircraft
- FDR was removed for data analysis

## November 2003: DHL A-300

- Departing Baghdad, Iraq with cargo, 3 crew onboard
- At 8000 feet a surface-to-air missile (SAM) hit the aircraft
- Missile did serious damage to left wing
  - Lost all hydraulic control
  - No.2 engine on fire
- Crew used TOC to control the aircraft for 16 minutes before landing
- All 3 crewmembers walked away



JetPhotos.Net - Image Copyright © DK

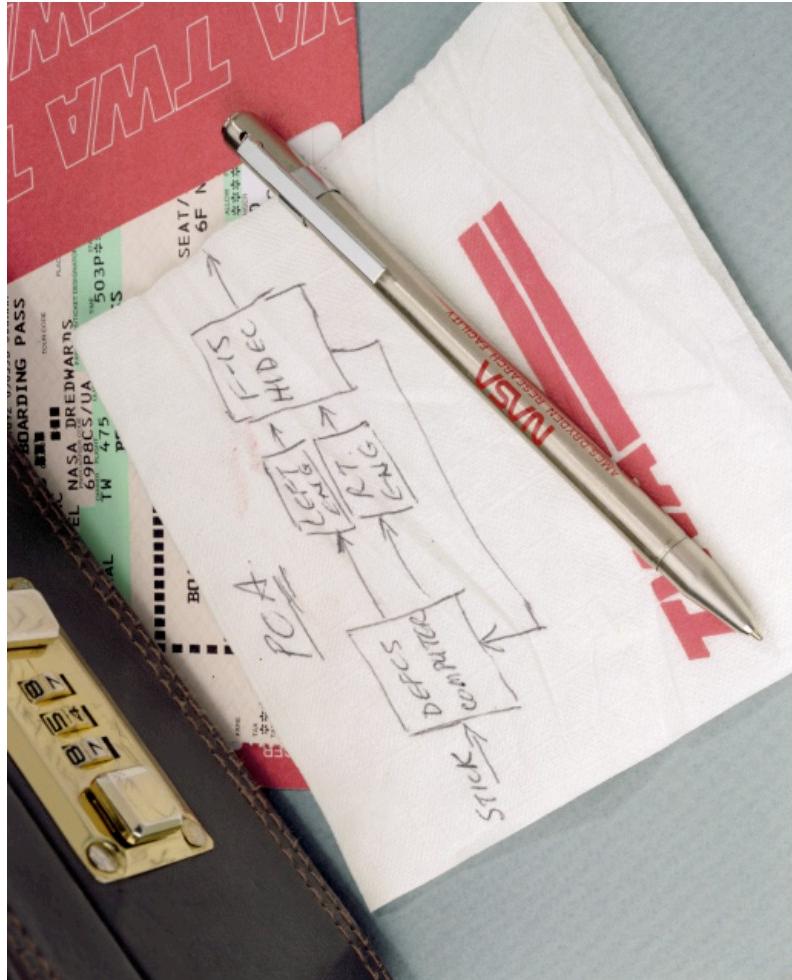


# Historically, TOC has saved lives

- Military showed initiative
- Commercial world has yet to initiate TOC procedures
  - JAL 123 and UAL 232 accidents
    - More detailed inspections
    - Improved repair procedures
    - More redundancy built into aircraft
  - But no initiative to recognize TOC as part of an emergency procedure
- Relative success of UAL 232 crew to control their aircraft with throttles inspired a NASA Dryden engineer to explore propulsive thrust as a means for automated control

# Automated Throttles-Only Control

- 1990s - Digitally controlled engines
  - Possible to create software to talk to the engines and control the aircraft using ***only propulsive thrust***
  - Propulsion-controlled aircraft (PCA) project was born



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>

NASA Photo: EC94-42805-1 Date: October 11, 1994 Photo By: Dennis Taylor  
<http://www.arc.nasa.gov/jsc/jsc.htm>

A simple sketch on a TWA napkin by NASA Dryden engineer Frank W. "Bill" Burcham led to development and validation of the Propulsion-Controlled Aircraft concept.

July 26 2006

AirVenture, Oshkosh 2006

# PCA Project

- PCA became a full-fledged Ames-Dryden initiative

- F-15 and the MD-11

- TOC was extensively demonstrated

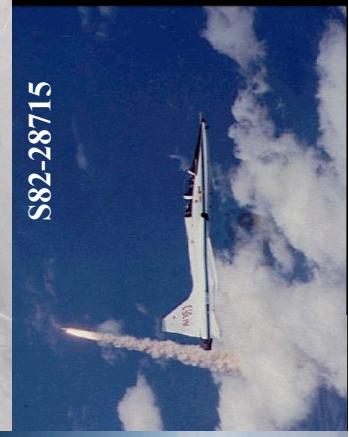
- Piloted simulations included

- Transport (B-720, B-727, B-757, MD-90, MD-11, B-747, C-17)
  - Fighters (F-15, F/A-18) and the SR-71
- Piloted flights included
  - Transport (MD-11, B-747, C-17)
  - Fighters (F-15, F/A-18)
  - Trainers (T-38, T-39)

biz jet and PA-30



EC97-43933-4



S82-28715



EC97-44272-6



ECN 2845



ECN-4242

# Propulsion-Controlled Aircraft

## MD-11 PCA Test Airplane

Ship 560, Test Team in Place at Yuma

Advanced  
digital cockpit

Extensive instrumentation  
recording, and display

Digital flight  
systems, data  
buses

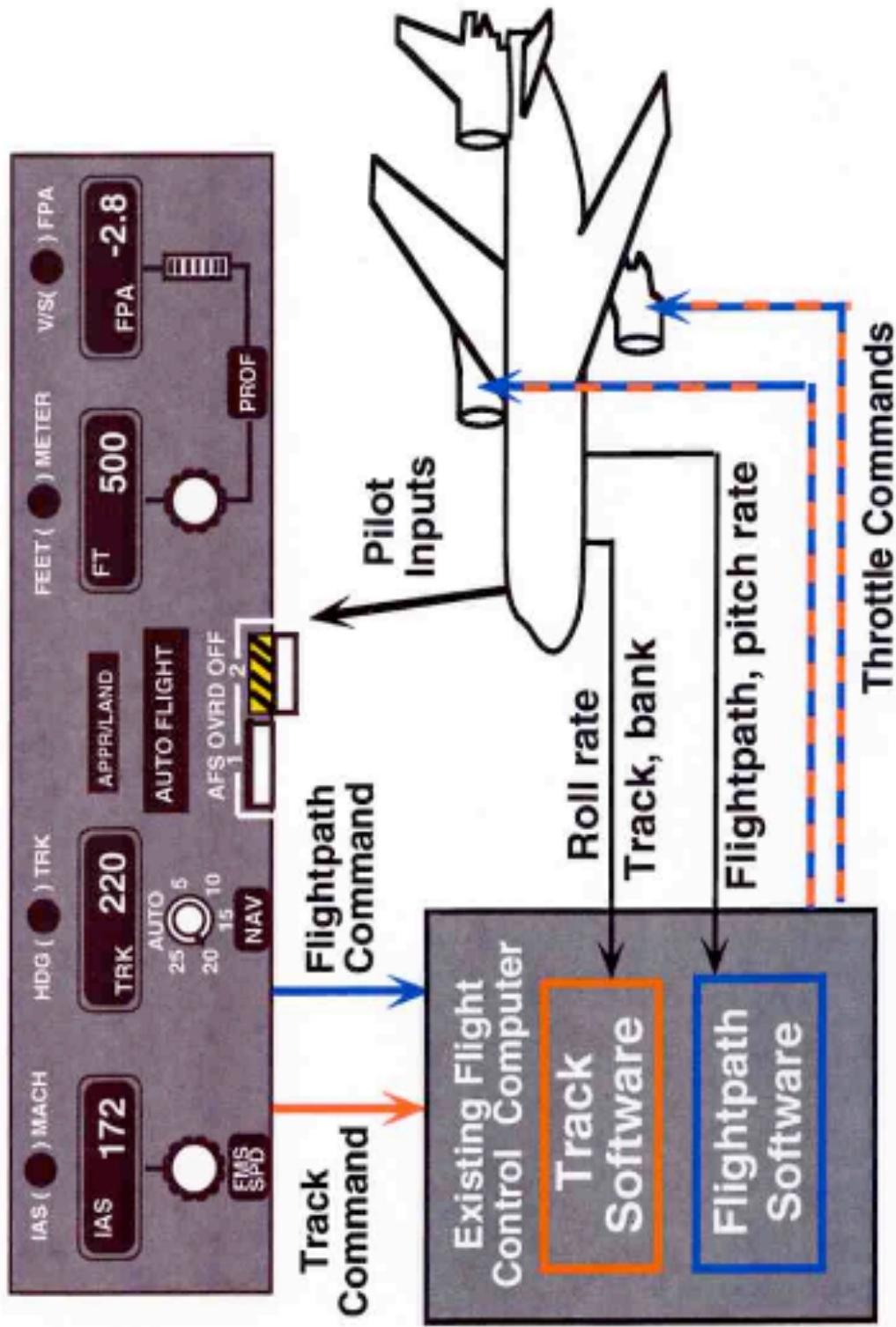
FADEC digital  
engine controls

Wing engines  
10 ft below  
the vertical CG



Dryden Flight Research Center

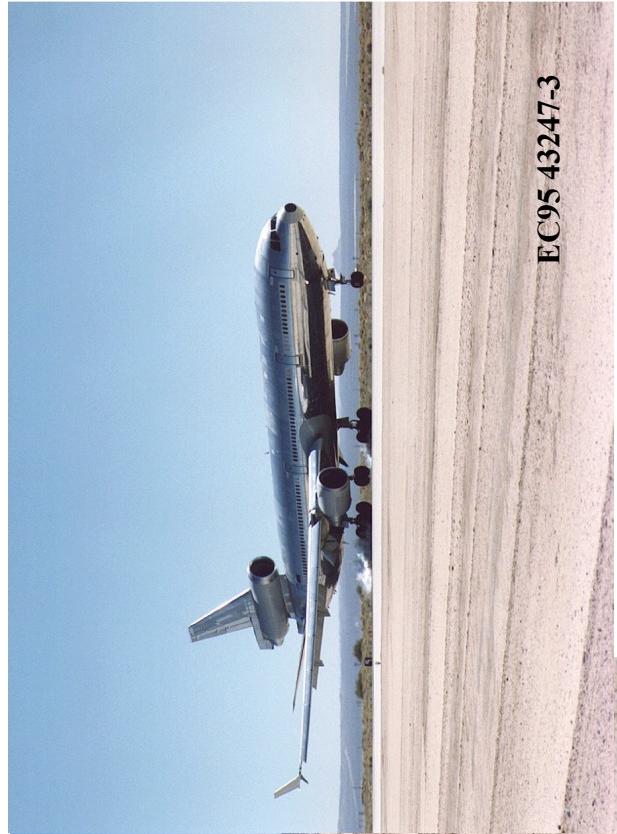
# MD-11 PCA System



NASA DRYDEN FLIGHT RESEARCH CENTER

# PCA Project

- PCA was demonstrated with the landing of an MD-11 *using only engine thrust for control!*
  - Gordon Fullerton on August 29, 1995
- Program continued to demonstrate ILS-coupled landings, envelope expansion to 30000', 360 KIAS and even *turning off hydraulics*



EC95 43247-3

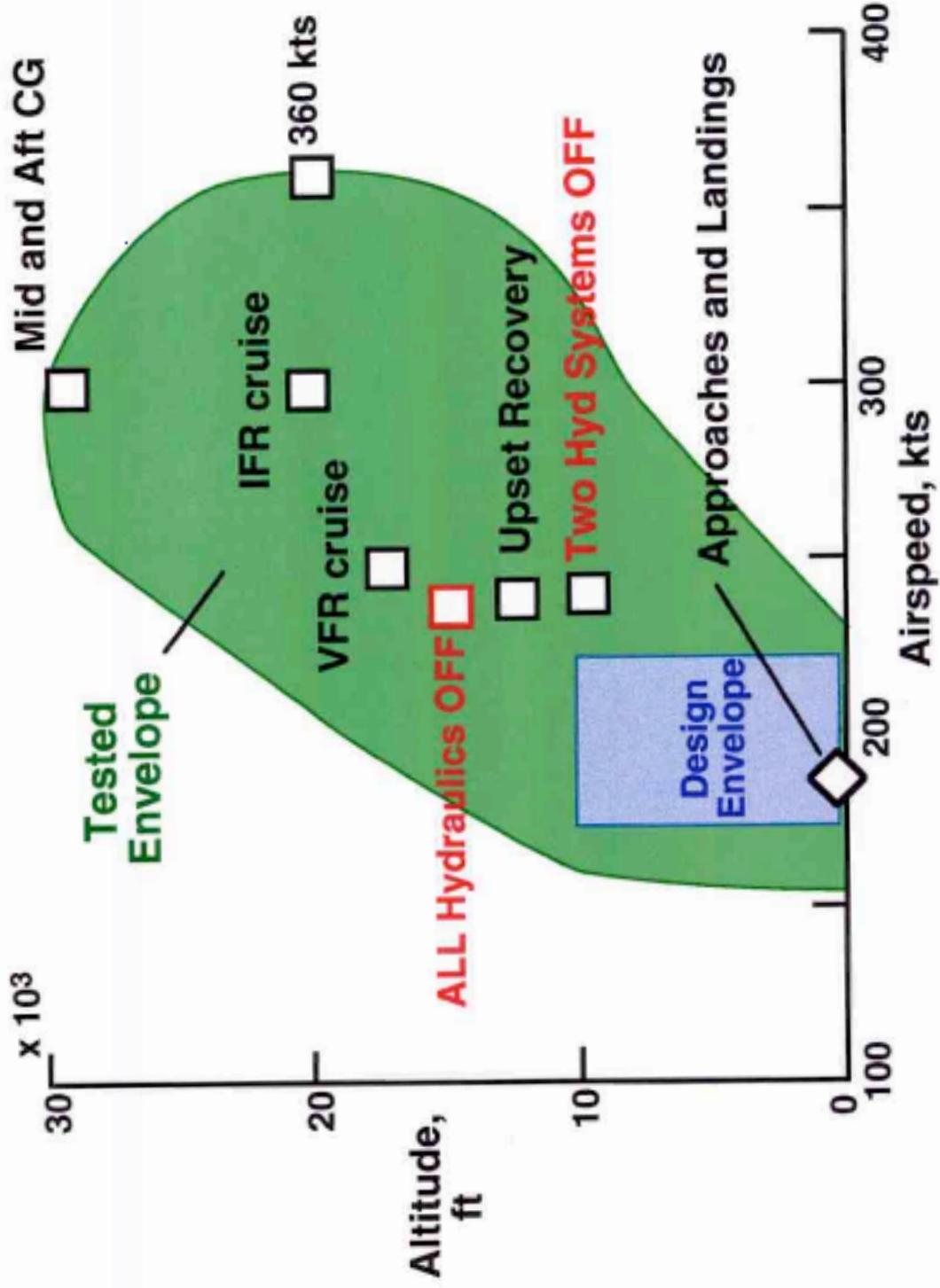


EC95 43247-1



EC95 43355-1

# MD-11 PCA Flight Test Envelope

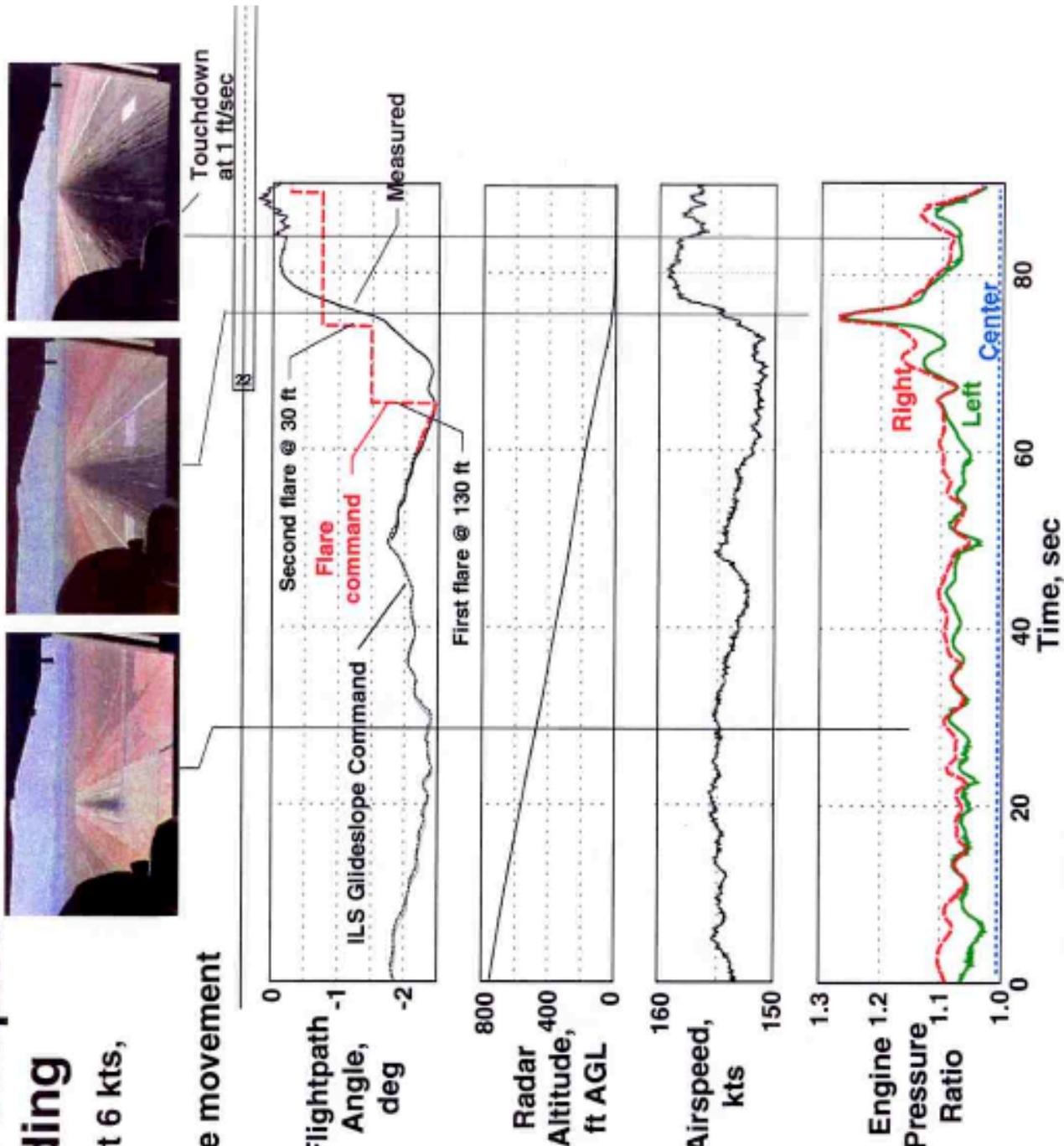


DRYDEN FLIGHT RESEARCH CENTER

# MD-11 PCA ILS-Coupled Hands-Off Landing

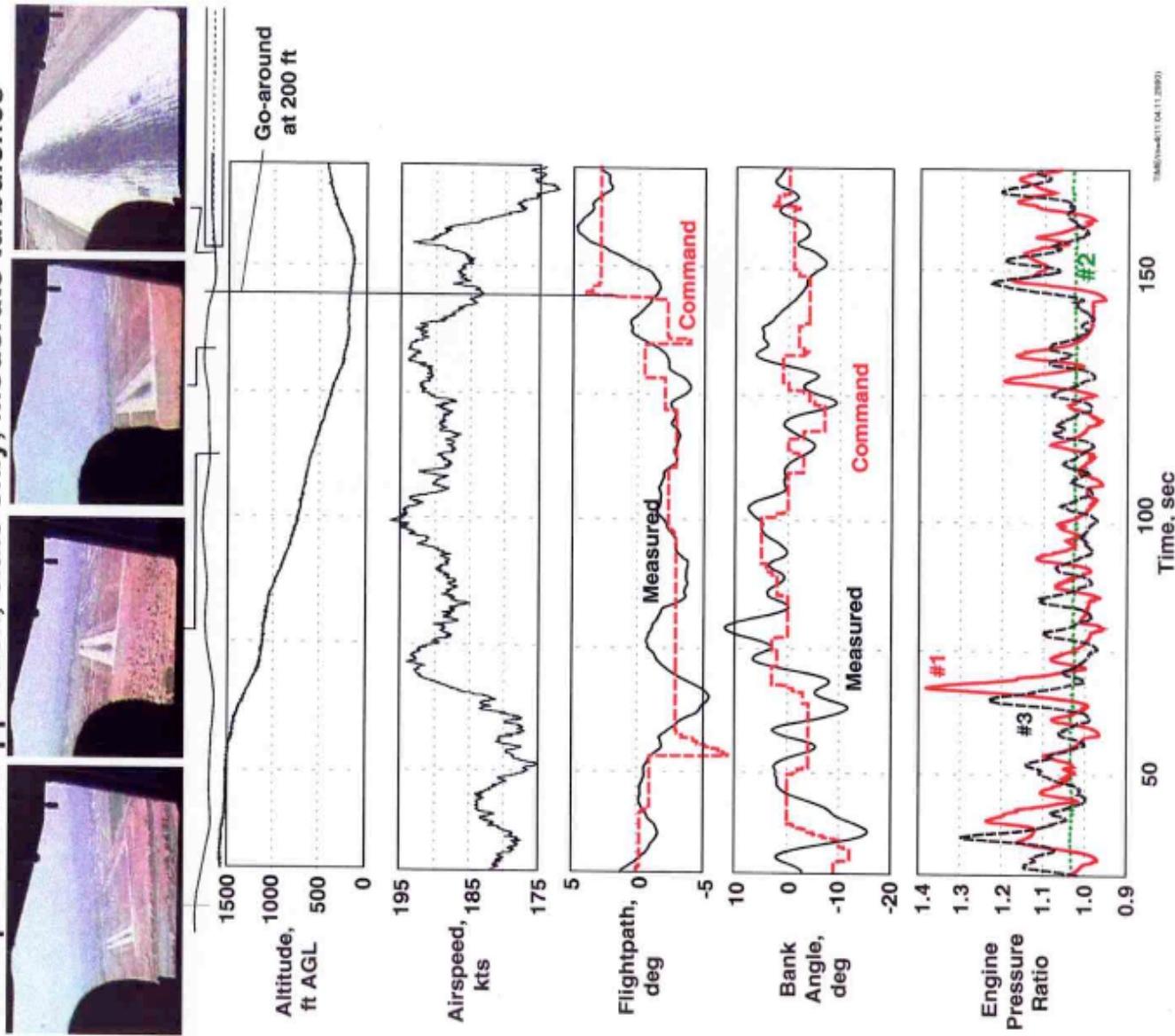
28° Flaps, winds 260° at 6 kts,  
no turbulence

No flight control surface movement



## MD-11 PCA Approach and Go-around

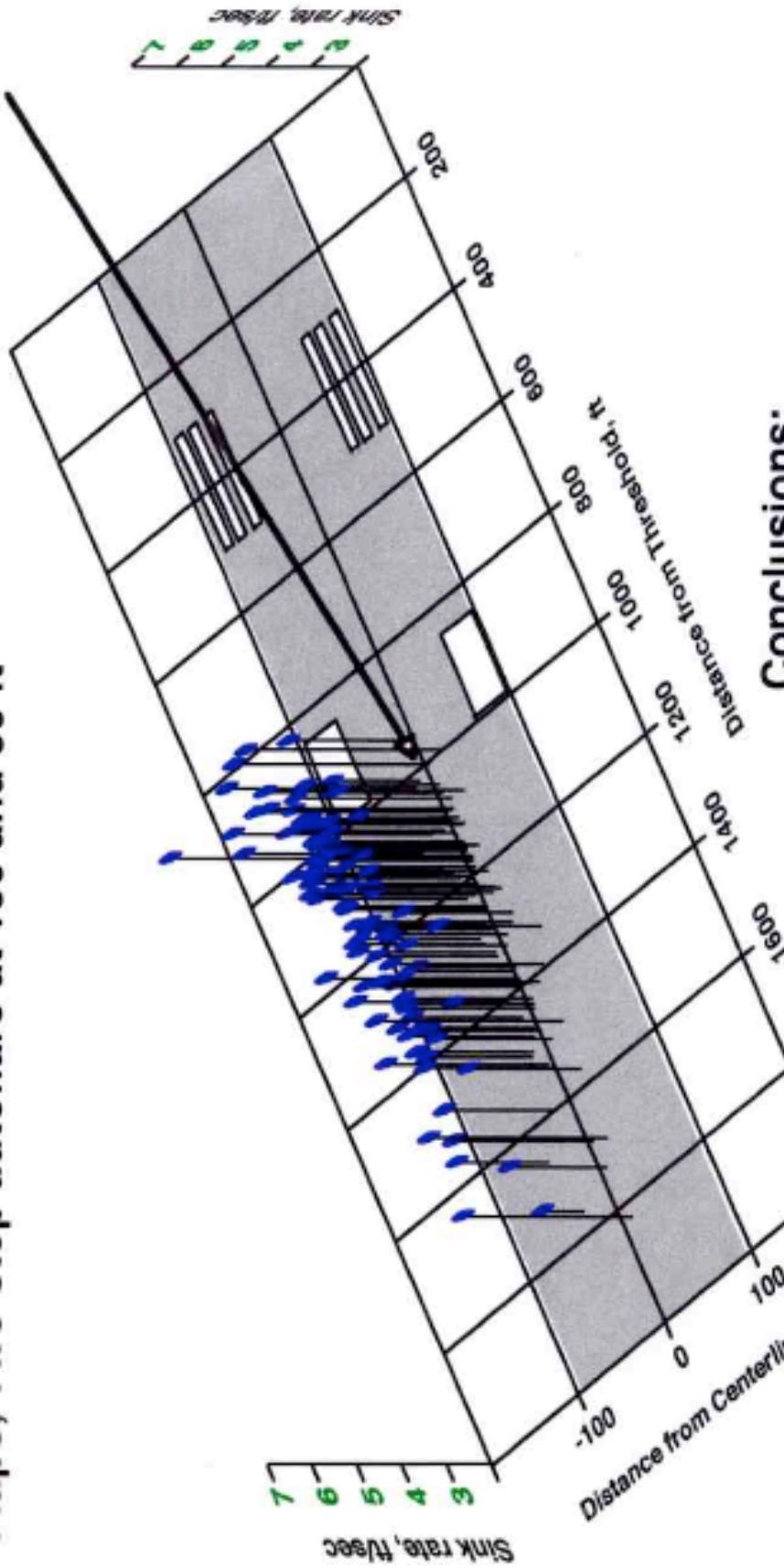
New pilot's 3rd approach, slats only, moderate turbulence



Not ILS-Coupled,  
Not pilot using the  
New pilot knobs in  
autopilot knobs in  
Moderate turbulence

# MD-11 Simulation, PCA ILS-Coupled Landing Dispersion

Hands-off landings, range of weather, weight, and CG, 100 landings  
28° Flaps, Two-step autoflare at 130 and 30 ft



## Conclusions:

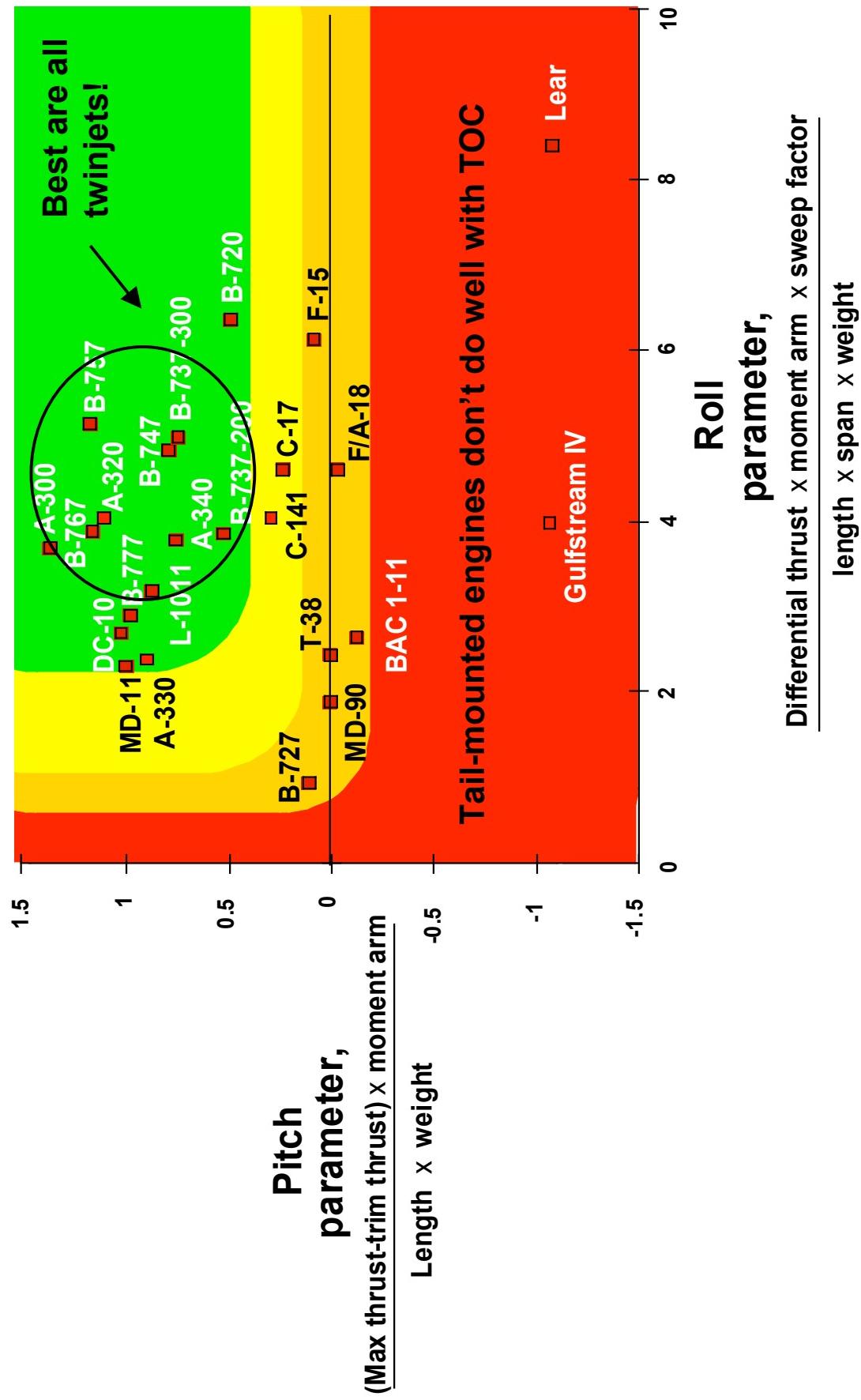
An ILS-coupled PCA system can make safe landings over a very wide range of conditions



# Throttles-Only Pitch and Roll Control Power

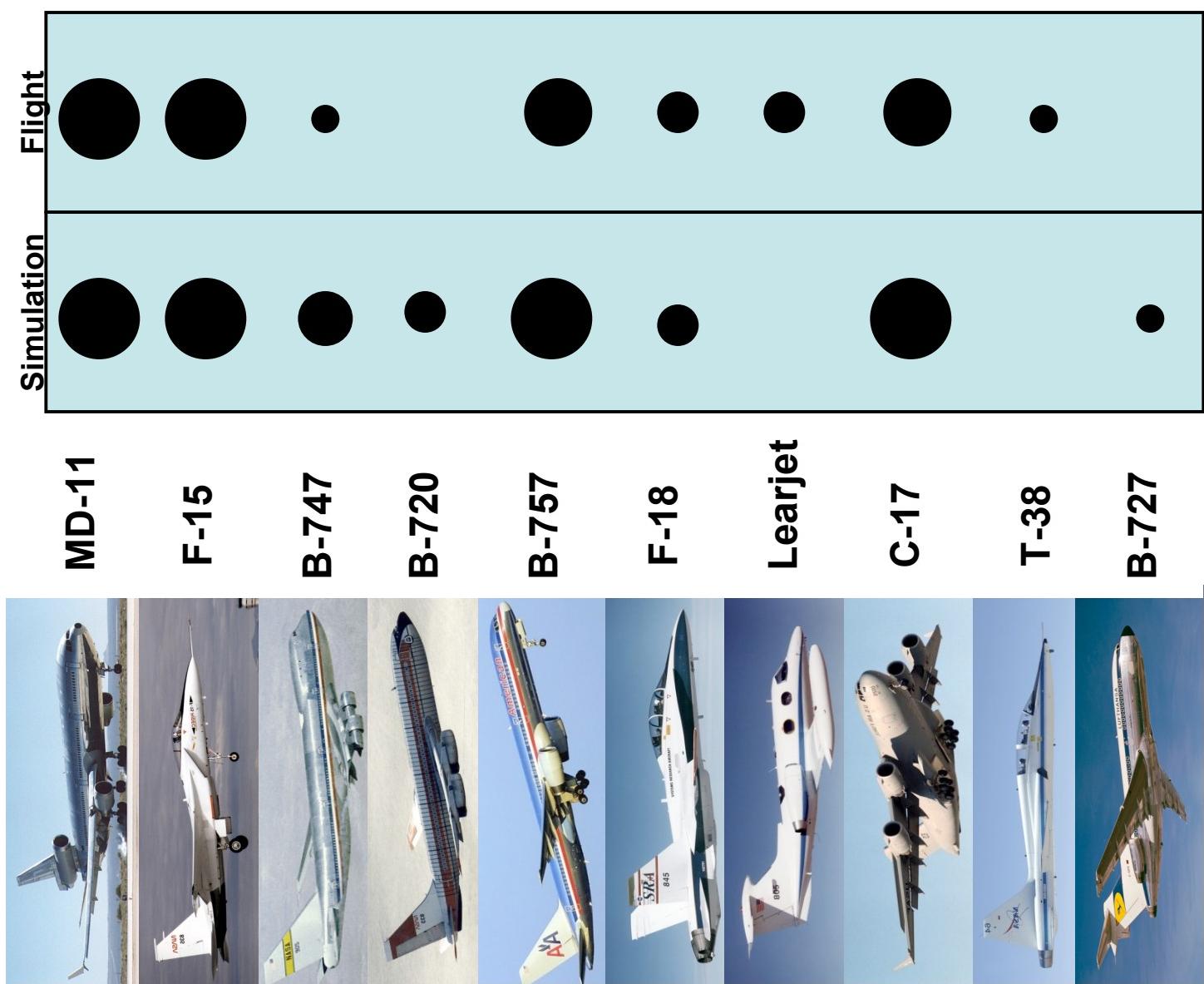
Maximum capability (without afterburning) 200 kts, low altitude

NASA  
FWB 01-19a



This chart depicts the relative amount of TOC research that has been performed on jet-powered configurations...

Borrowed from FWB 2/06



# PCA in Commercial Fleet...?

In 1996, PCA was beneficial for many reasons

- Enabled an aircraft with damaged flight controls to safely land
- No additional weight (just software was loaded on the aircraft)
- Repeatable, survivable results over a wide variety of conditions
- Demonstrated to 21 airline, DoD, FAA, Boeing and Airbus pilots
- Useful in a variety of situations
  - Structural or control system failure, loss of hydraulic fluid, damage, etc.

So why didn't PCA ever make it on any aircraft ?

- Potential cost of certification
- Industry climate at the time disliked any retrofit systems
- Potential liability issues with airframe manufacturers

# Fall 2005: PCAR Project

In the post-9/11 world, DHS has sponsored an effort to bring both PCA and TOC to the commercial fleet

- PCAR = Propulsion-Controlled Aircraft Recovery
- PCA
  - Transfer previous PCA experience to 747-400
  - Working with industry experts to integrate PCA into current fleet
  - Effort is on-going
- TOC
  - Aircraft controllability and recovery
  - Initial look at B-757

# PCAR Background - TOC



- Joint DHS/UAL/NASA effort
- Provide pilots with another tool in their ‘toolbag’
  - Wind shear, evasive maneuvers, similar to existing emergency procedures
- Developing Throttles-Only Control techniques for commercial fleet
  - Current focus on the 757-200
- Research group comprised of pilots and engineers from NASA and UAL
- Deliverable: Generate TOC product for the 757-200 aircraft
  - Test and line pilot evaluated, in both simulation and flight

# PCAR Background - TOC

- Evaluate effectiveness of TOC on the 757
  - 64 hours in sim, 4 hours in flight so far
- Results so far indicate that TOC on 757-200 is very favorable
- Initial Findings For 757
  - Aircraft is very responsive to thrust control
    - Add thrust = slow down, but climb
    - Reduce thrust = speed up, but descend
  - During the landing flare - *add* thrust
- New pilots conducted survivable landings on their first try
  - Landings are often 200+ KIAS
  - Just like in real-life TOC events - practice, practice, practice
- VSI is valuable tool for establishing trim speed and general TOC maneuvering

# PCAR Background - TOC



- Finish Phase I by end of FY06
  - 30 hours of simulations, 5 more hours of flight
  - TOC checklist evaluated by UAL 757 test and line pilots
- Enter Phase II
  - Extend TOC investigation on 777, 767, A320 platforms
  - Determine candidate platform for further TOC development
  - Spend 50 hours simulation, 2 flights to generate TOC checklist

# PCAR Summary



- Working to get proven technology into the commercial fleet
- Controlling an aircraft using propulsive thrust is beneficial
  - Is independent of failure (structural, control system, damage, etc)
- TOC applies to older, less digital aircraft
- PCA would be a relatively easy add-on for newer aircraft
- Pilots and aviation advocacy groups support the technology
- JAL 123, UAL 232 and C-5A crashes alone claimed over 1100 lives
  - How many more could have been saved with PCA/TOC technology?

Any Questions?

